

# Advanced Photon Source Upgrade Path

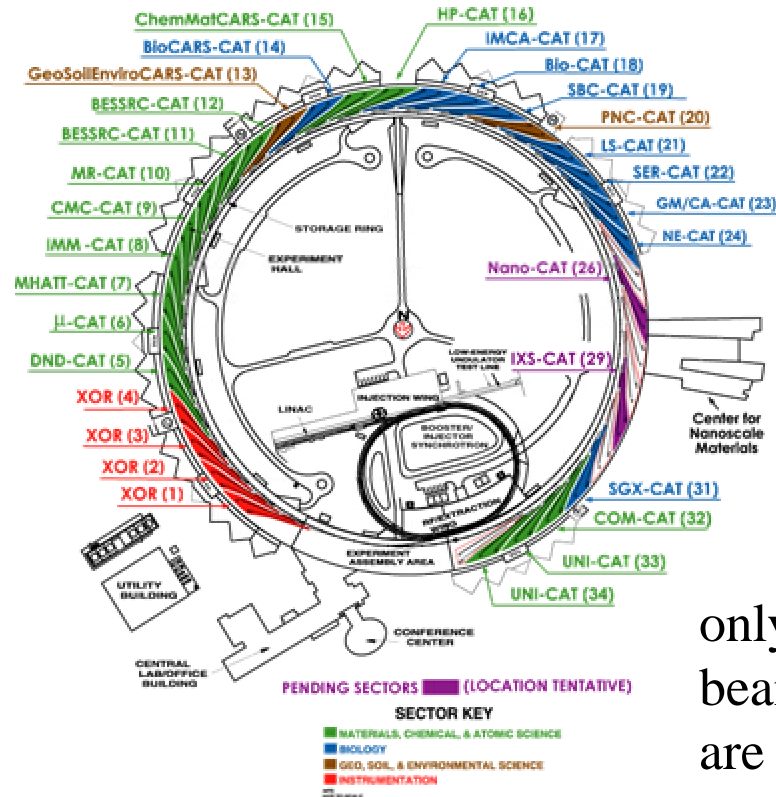
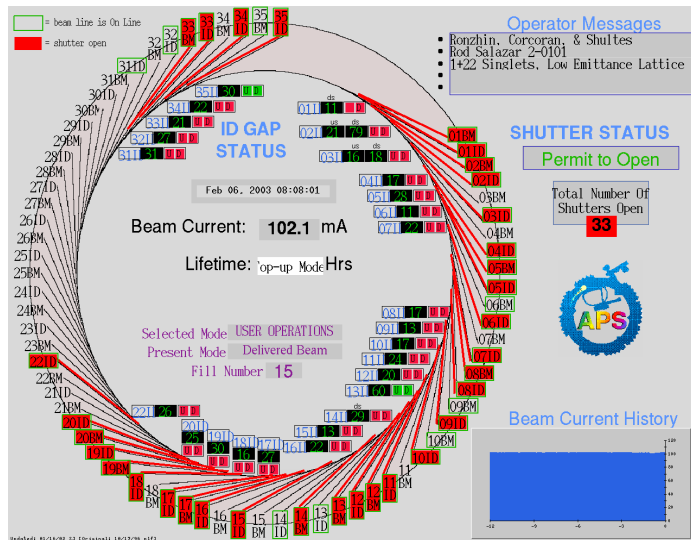
*Defining the State-of-the-Art*

Presented to BESAC Subcommittee  
on 20-year Facilities Roadmap

February 23, 2003

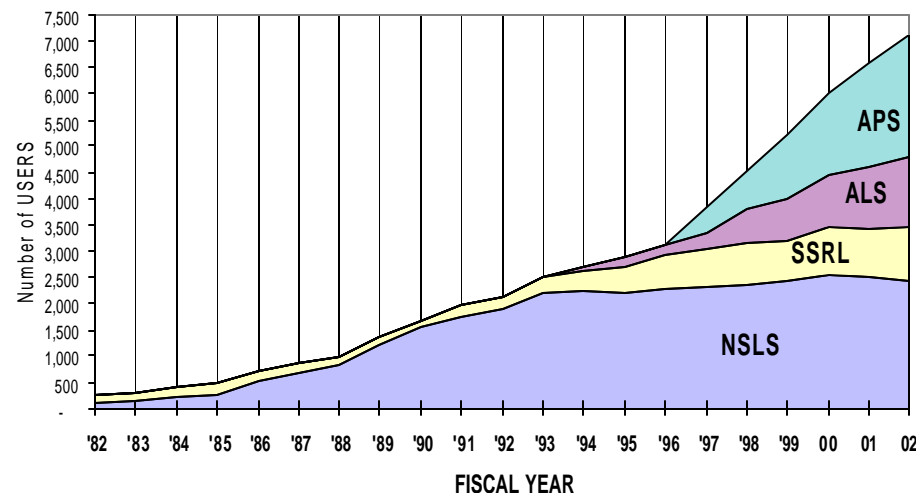
By J. Murray Gibson

# APS Today



only 4 ID beamports are not yet committed

38 functioning beamports  
(25ID, 13BM)  
68 total available



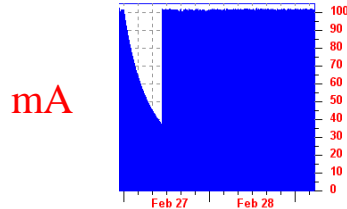
APS user community to reach ~10,000 in a decade

# State-of-the-Art 3<sup>rd</sup> Generation Science in 20 Years?

- *Individual* nanoscale objects can be observed in *real-time*
- Electronic, dynamic and magnetic properties of a *single nanostructure* can be measured
- *A few atoms* can be chemically identified
- A full dataset for protein structure analysis can be collected in *less than a second*
- X-ray imaging of objects with *nm resolution* is routine

# History of Innovation

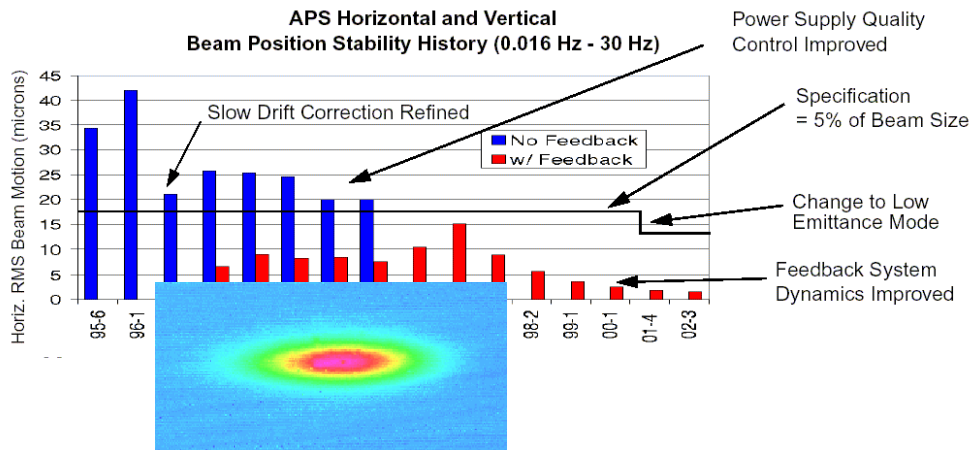
- Top-up operation



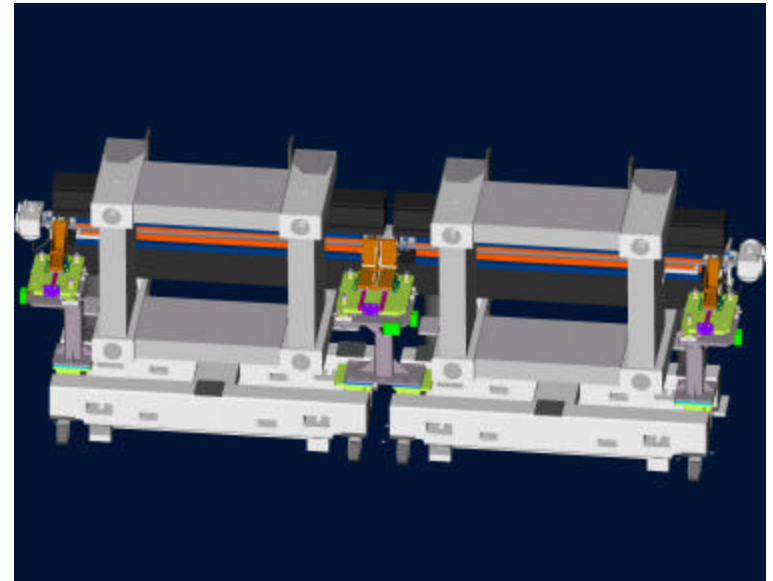
–*Low emittance*

–*Stable optics*

- Improved beam stability



Canted  
Undulators



- *driven by bio users*

# Guiding principles for next 20 years

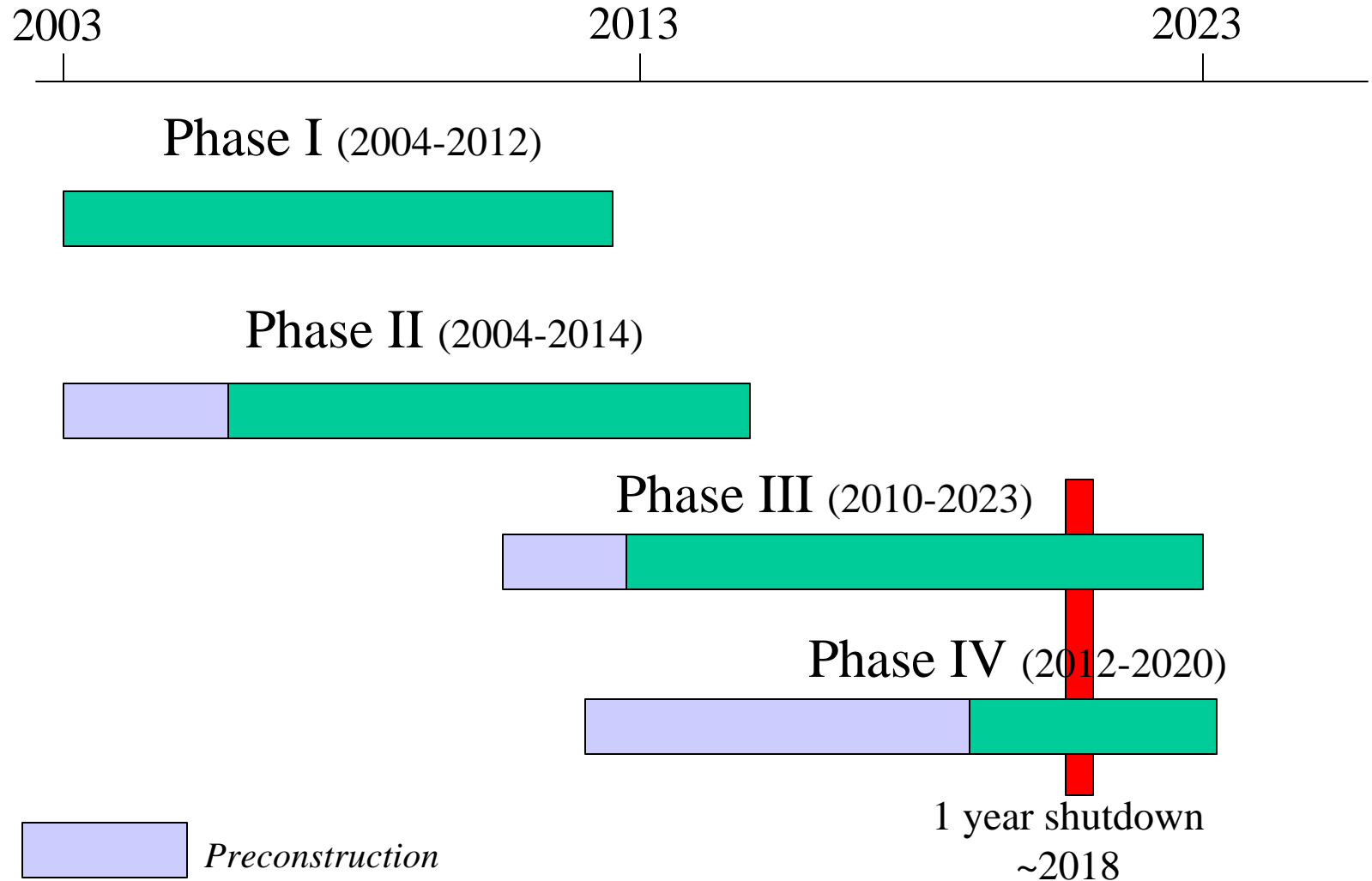
- The mission of the Advanced Photon Source is to deliver world-class science and technology by operating an outstanding synchrotron radiation research facility accessible to a broad spectrum of researchers
- Need for 3<sup>rd</sup> Generation Sources will not go away in 20 years, and our user base will grow to ~10,000
  - 4<sup>th</sup> generation is revolutionary, but does not supercede 3<sup>rd</sup> generation
- Our users and staff should be connected with the next generation capabilities
  - short pulses (fs), higher coherence.
- APS capabilities must increase continually
  - over 1000 times improvement in “useable” brilliance possible within 20 years
- Maintain strong partnerships (such as CATs), and open access for general users

*Defining the state-of-the-art in 3<sup>rd</sup> generation x-ray sources and science*

# APS phases of innovation in the next 20 years

- Phase I – Maximizing Beamline Operations
  - Phase II – Maximizing Source Capabilities
  - Phase III – Next Generation Facility
  - Phase IV – Super Storage Ring
- Phases II, III and IV each represent at least an order of magnitude increased useable brilliance

# APS Upgrades Timeline



# Phase I – Maximizing Beamline Operations (2004-2012)

- 10 beamlines to be constructed in the next 8 years (5 years per beamline)
  - more than 1 beamline possible per beamport
- 10 beamlines to be upgraded
  - most likely BES sectors (~26 beamports)
- Construction
  - APS and partner user responsibility
- Operation
  - APS responsibility

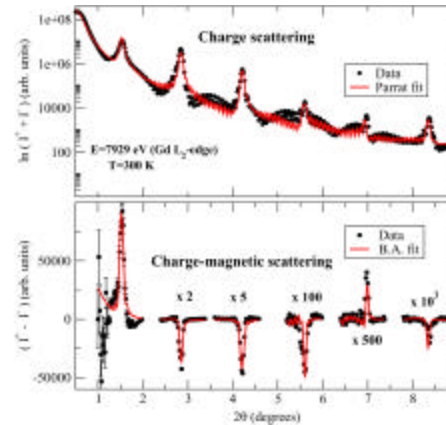
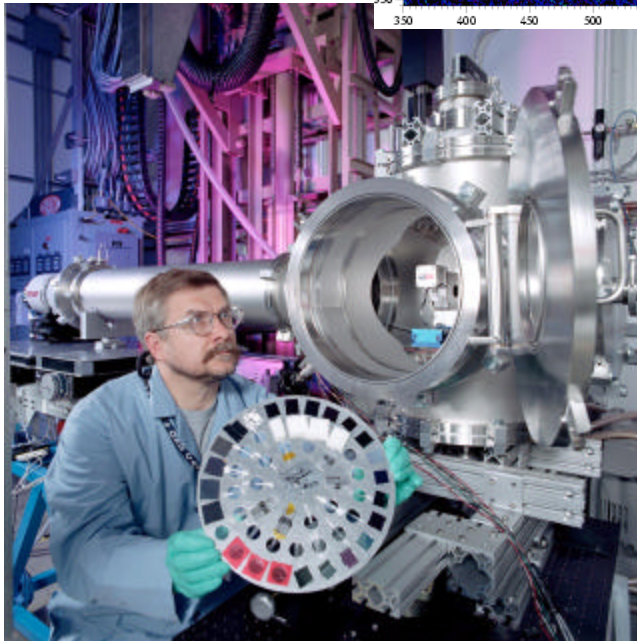
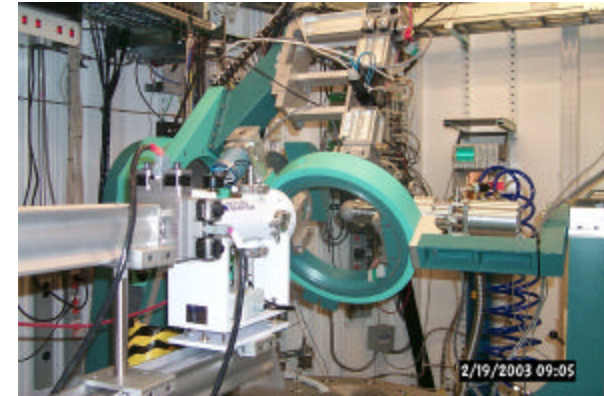
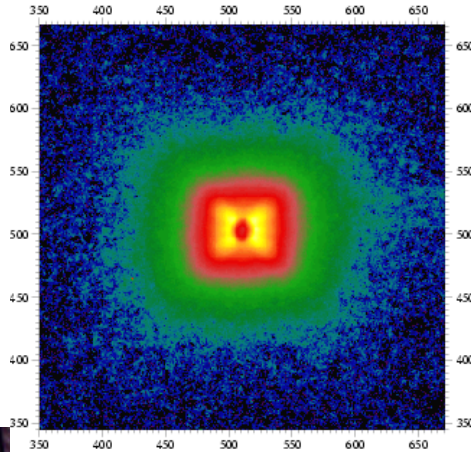


# The Importance of the Science

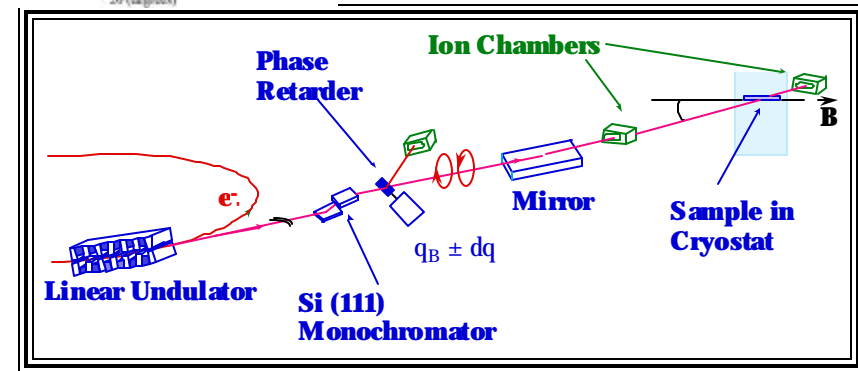
- New capabilities will be optimized (in parallel with optimized sources during Phase II)
- All beamlines will be well operated and accessible
- Quantity and quality of output will increase
- Science Advisory Committee oversees choices

# Two kinds of beamlines:

*a “turnkey”  
beamline to  
efficiently  
collect - SAXS*

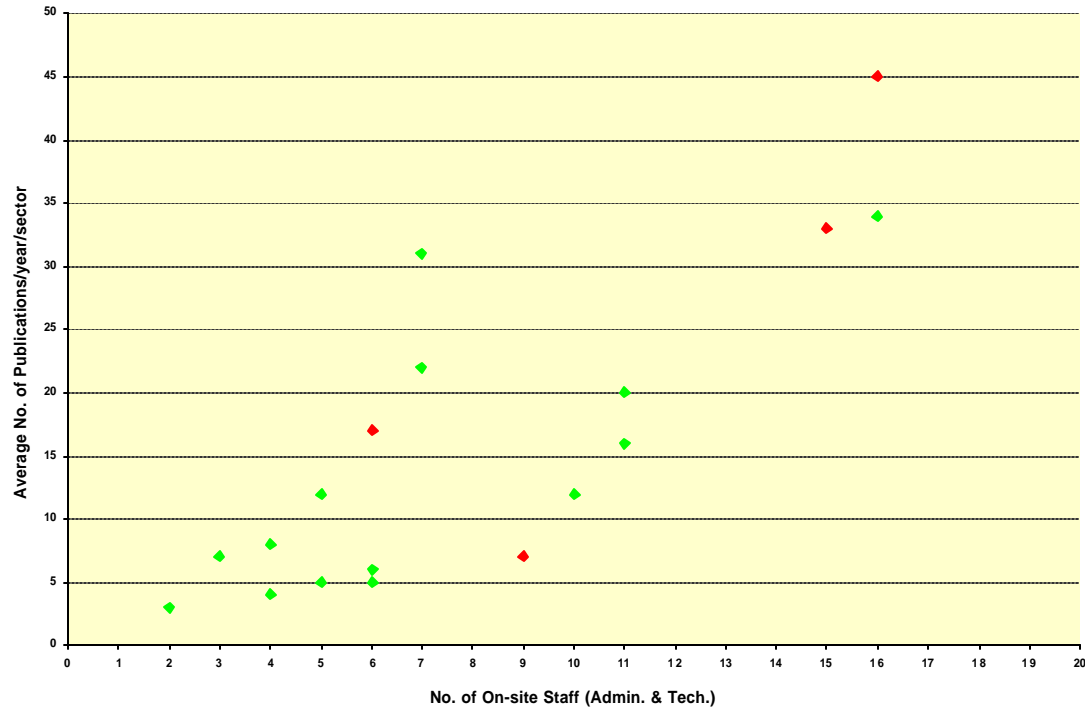


*a dedicated  
beamline to  
“do experiments” -  
magnetic scattering*



# Beamline operation support leverages science

Average Number of Publications/year/sector vs. On-site Staff\*

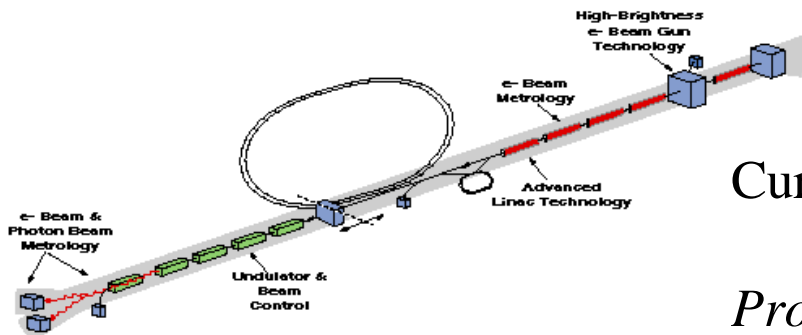


# Readiness for Phase I

- Beginning now but limited by resources
- Capital resources and manpower for operations
  - our current staff level permits insertion device development and some beamline design assistance ~1/3 beamlines
  - operational staff support must grow by ~100 people (+20% current operating budget)
- Continuing incremental improvements in detectors, optics will occur during Phase I
- VUV-FEL facility is a special beamline -

# APS “LEUTL” FEL beamline

- Allows accelerator physics activities such as gun development for 4<sup>th</sup> generation
  - demonstrated SASE at ~100nm
  - operates independently in non-top-up mode
- VUV-FEL user facility for ~\$10M



Currently serving a single user:

UV single-photon ionization

*Proposed facility offers better capabilities,  
more users and complete independence from SR*

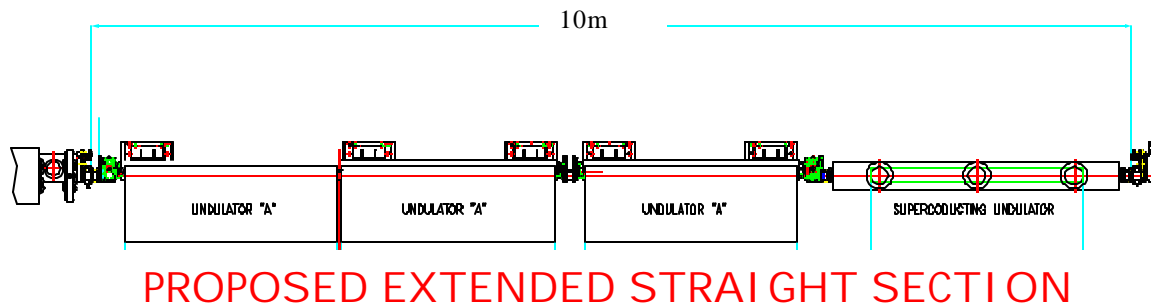
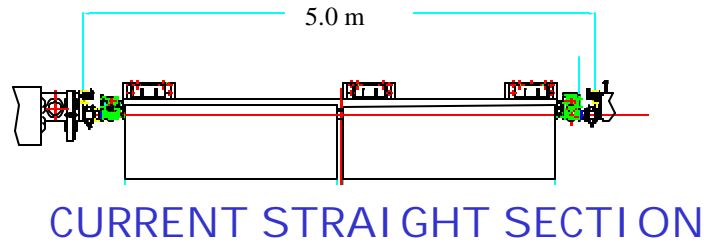
# Phase I – Cost, Schedule, Scope and Management

- Estimated cost \$160M over 8 years
  - average 2-3 new beamlines per year, up-front weighting on new beamlines
- Funds for new instruments should be ½ inside, ½ outside facility (for partnering)
  - With research funds outside
- Operational funds should be inside facility (~\$20M extra in today's dollars)
- SAC role, external peer review also on partner proposals

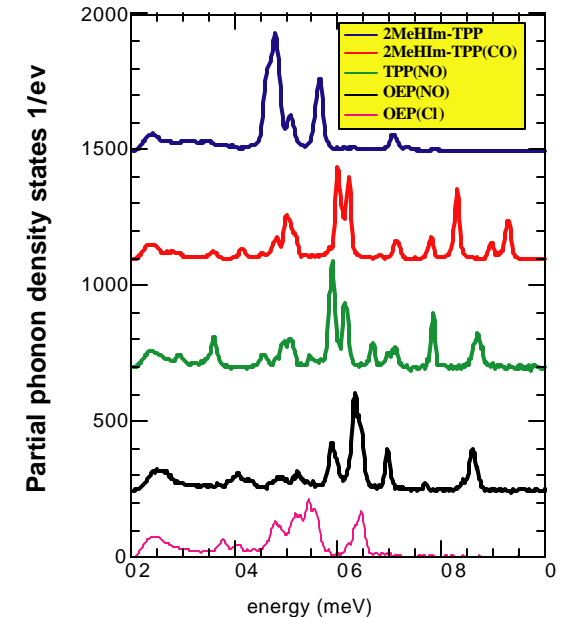
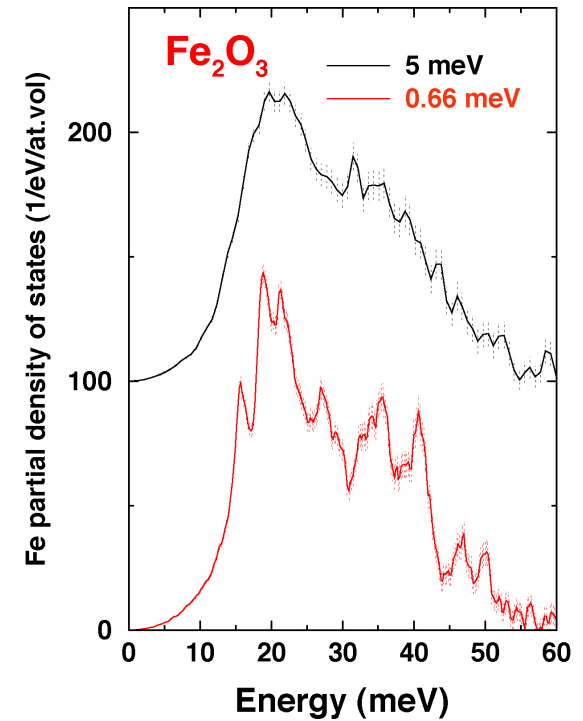
# Phase II – Maximizing Source Capabilities (2004-2014)

- Innovative undulators, front ends and related components
- Higher brilliance, optimized for application
- Improve front ends and high-heat load optics for higher current operation
  - APS operates at 100mA, would reach 300mA at end of Phase II
- Increasing brilliance by more than an order of magnitude
- Continuing accelerator improvement
  - even greater improvement beam stability

# Science Example -Extended straight section and inelastic x-ray spectroscopy



LONG STRAIGHT SECTION WITH THREE UNDULATORS "A" AND ONE SUPERCONDUCTING UNDULATOR

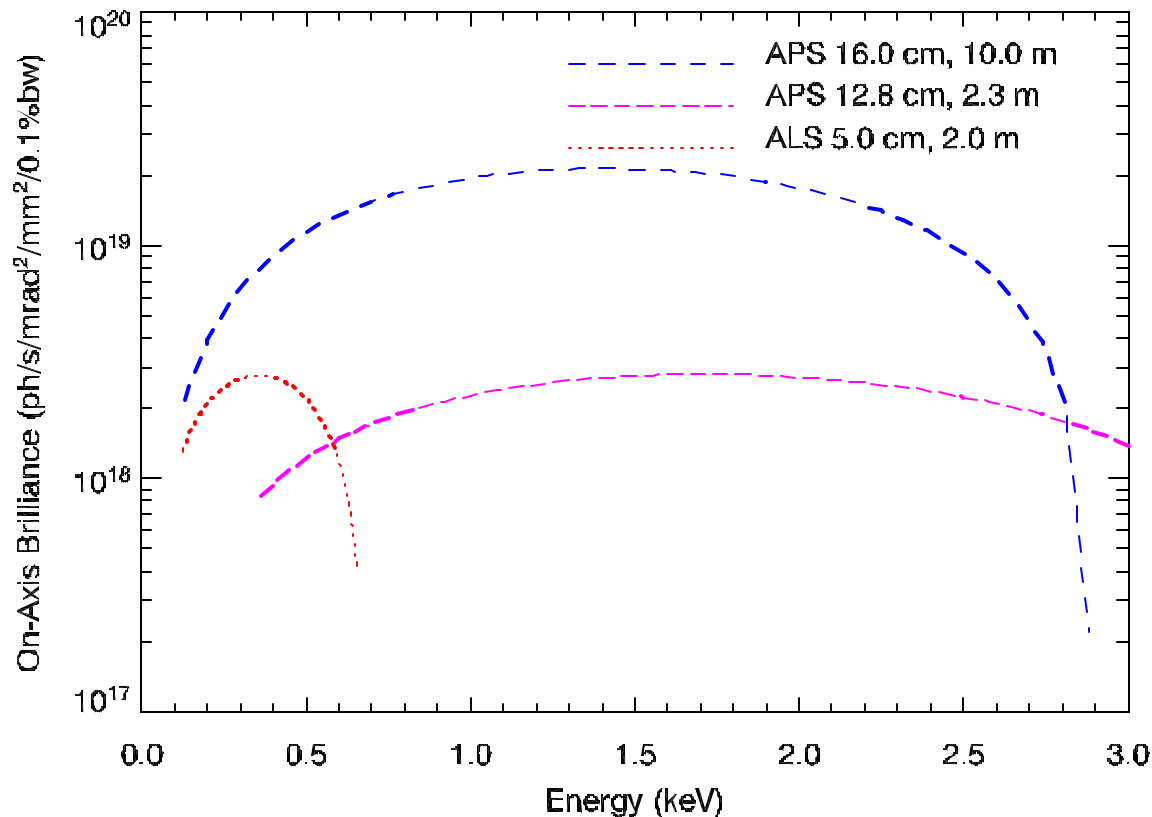


- The heme doming coordinate in myoglobin is directly involved in the oxygen-binding reaction
- Doming modes are expected in the range of 6-8 meV
- With a high enough resolution it becomes possible to study the influence of addition of ligands to the functional behavior of proteins



# Science example - magnetic studies with soft x-rays

## Brilliance Tuning Curves for Elliptically Polarized Devices



### Advantages of high energy rings:

- Low emittance
- High beam stability
- Large energy tunability

⇒ **Superior performance**

APS (7 GeV, 100 mA): 10 m long straight section,  $\lambda = 16.0$  cm,  $N = 62$

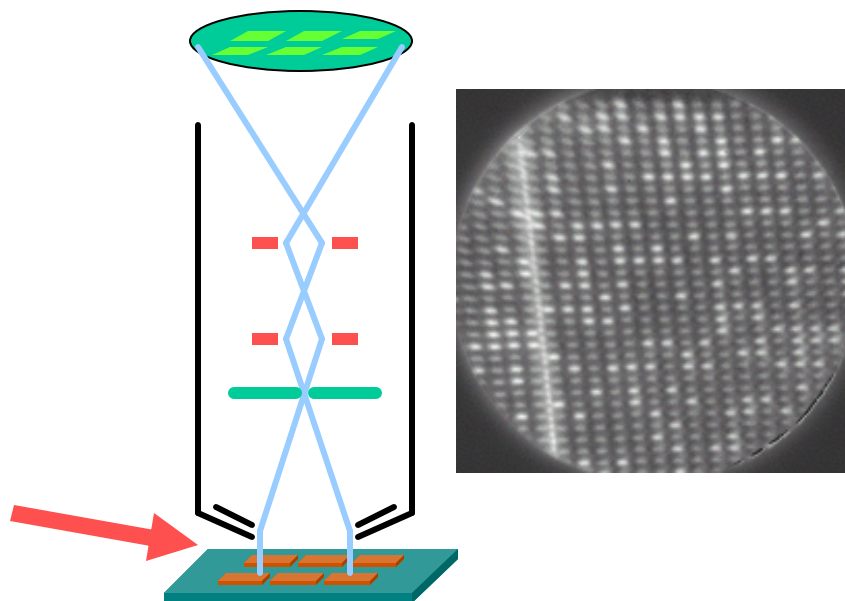
APS (7 GeV, 100 mA): 5 m long straight section,  $\lambda = 12.8$  cm,  $N = 18$  (current device)

ALS (1.9 GeV, 400 mA): 2 m long straight section,  $\lambda = 5.0$  cm,  $N = 37$

# Polarization-dependent spectroscopy

Helicity dependent X-ray emission provides information concerning spin polarized density of bulk occupied states

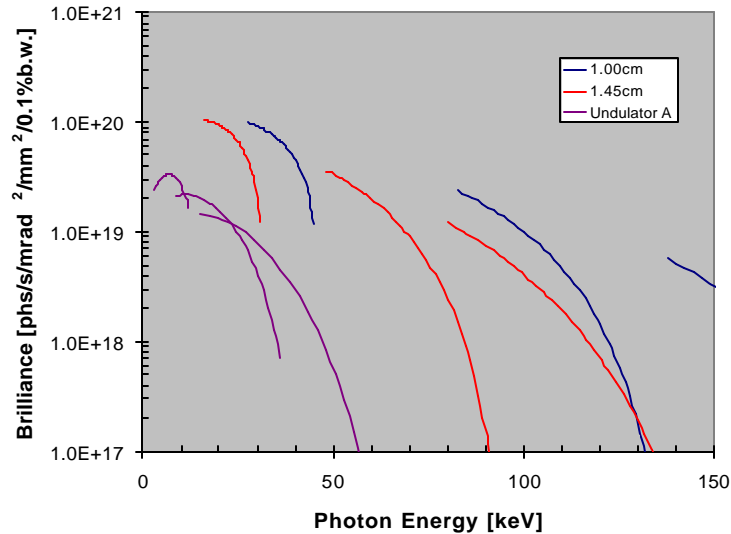
## Photoemission Microscopy



Spatial resolution target of 2 nm

- Magnetic contrast:
  - Domain imaging
  - Ground states in nanoscale systems
  - Interactions in particle arrays
  - Finite size effects
- Chemical contrast
  - Self-assembled systems
  - Segregation
  - Local electronic structure
  - Buried layers (~5 nm)
- Soft x-ray advantages:
  - High magnetic contrast
  - Access to TM, RE, semiconductors

# Readiness for Phase II - *Current R&D*

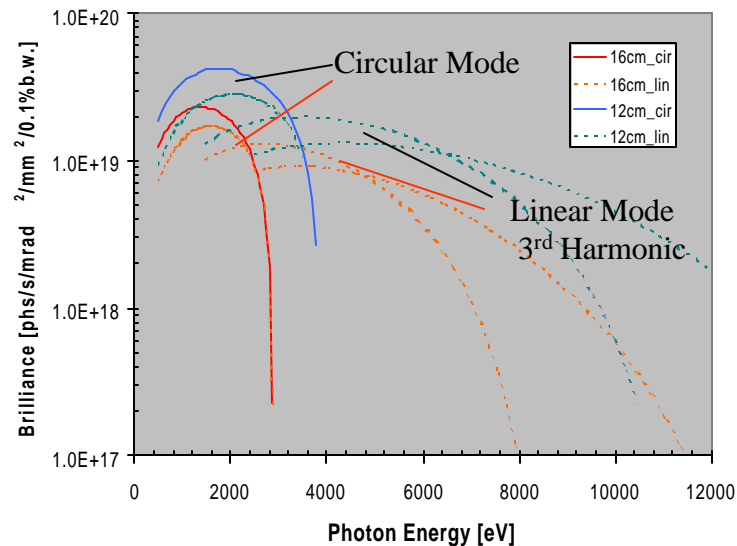


## Superconducting Small Period Undulator

1.45 cm period  
L=2.4 m, N=165  
Gap=7 mm  
Maximum K = 1.4

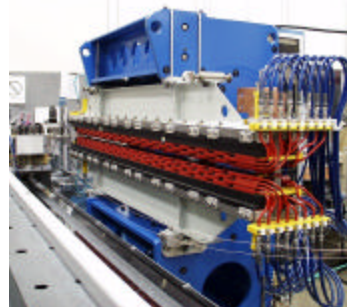
1.00 cm period  
L=2.4 m, N=240  
Gap = 3 mm  
Maximum K = 1.17

## Variable Polarization Undulator



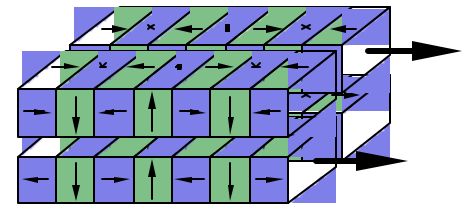
## Electro-magnetic Device

$\lambda=16$  cm, L=10 m, N=62



## APPLE type PM Device

$\lambda=12$  cm, L=10 m, N=82



Assumed APS storage ring parameters: 3.5 nm-rad, 1% coupling, 100 mA

# Phase II – Cost, Schedule, Scope and Management

- \$100M over 10 years, ramping up from \$5M per year in the first year, to \$20M in the last year
- APS will remain at the state-of-the-art in insertion device design
  - Connection with LCLS and other 4<sup>th</sup> generation sources

# Phase III – Next Generation User Facility (2010-2023)

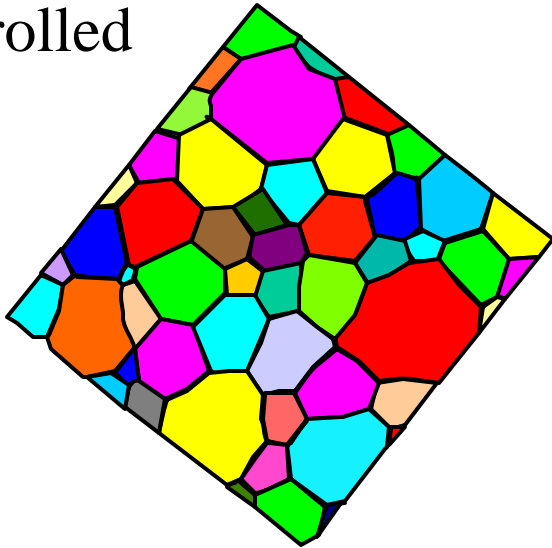
- By 10 years from now user community will approach 10,000
- APS will be primary 3rd generation hard x-ray source, with great capabilities and easy accessibility
- Need to develop beamlines and automation to reach next level

# The Importance of the Science

- Current performance is limited by beamlines – optics, detectors
  - One or two orders of magnitude improvement available in many cases
- Automation offers both remote access, better user support and new experimental capabilities

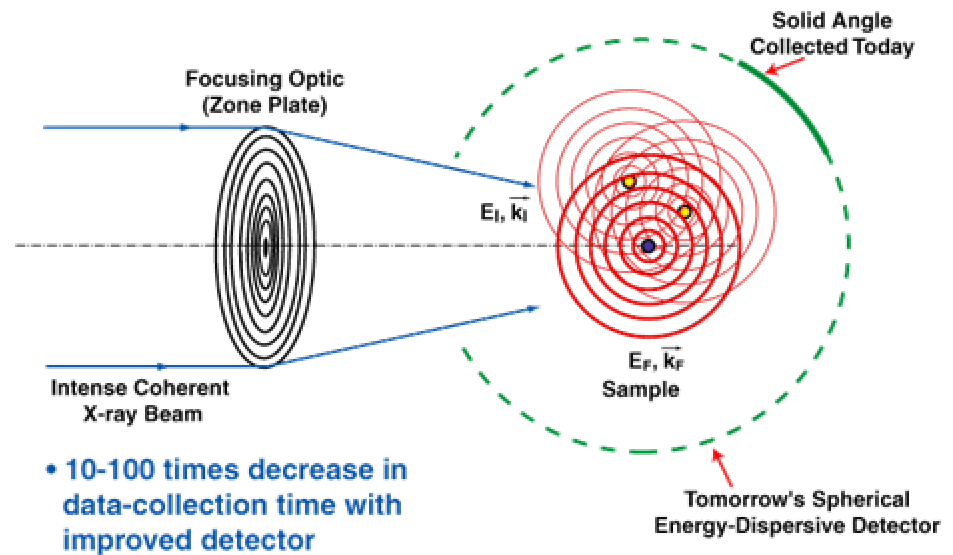
# Detectors and Optics Limit Performance

Hot-rolled  
Al



Map grain orientation and stress in  
real samples  $10^4 \mu\text{m}^3$  at  $1 \mu\text{m}$  resolution  
takes 54 hours to collect data  
CCD read-out time = 52 hours

## Atomic Resolution Fluorescence Holography

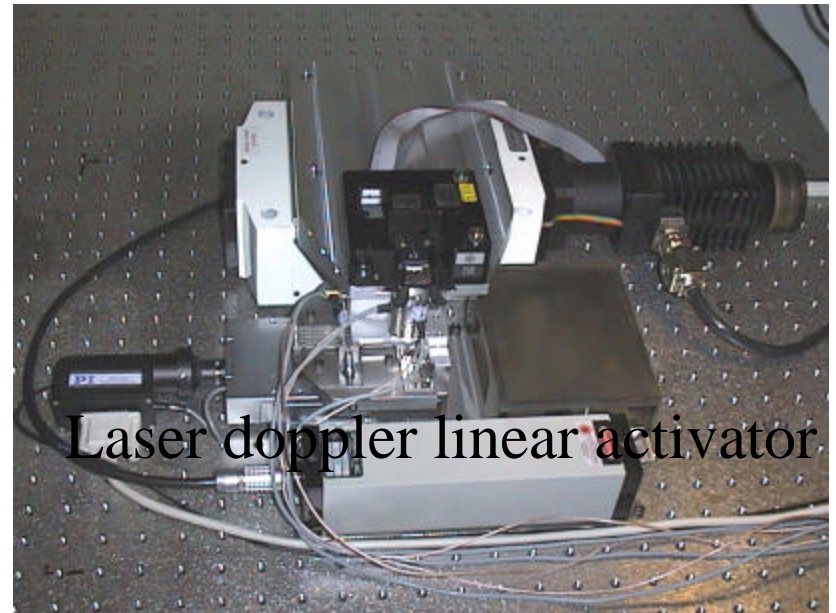
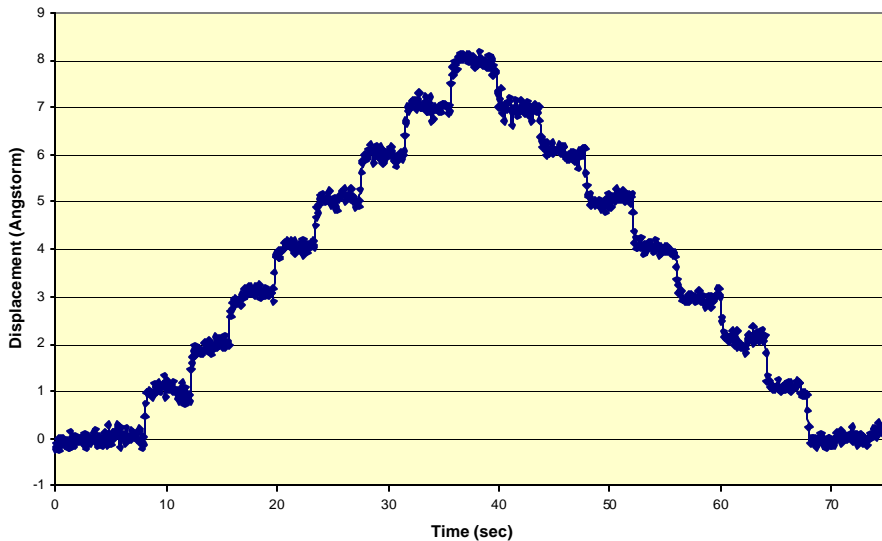


# Automation

- Not just remote access and user support
- Precision and control exceeds human capabilities

Laser Doppler Linear Actuator Test

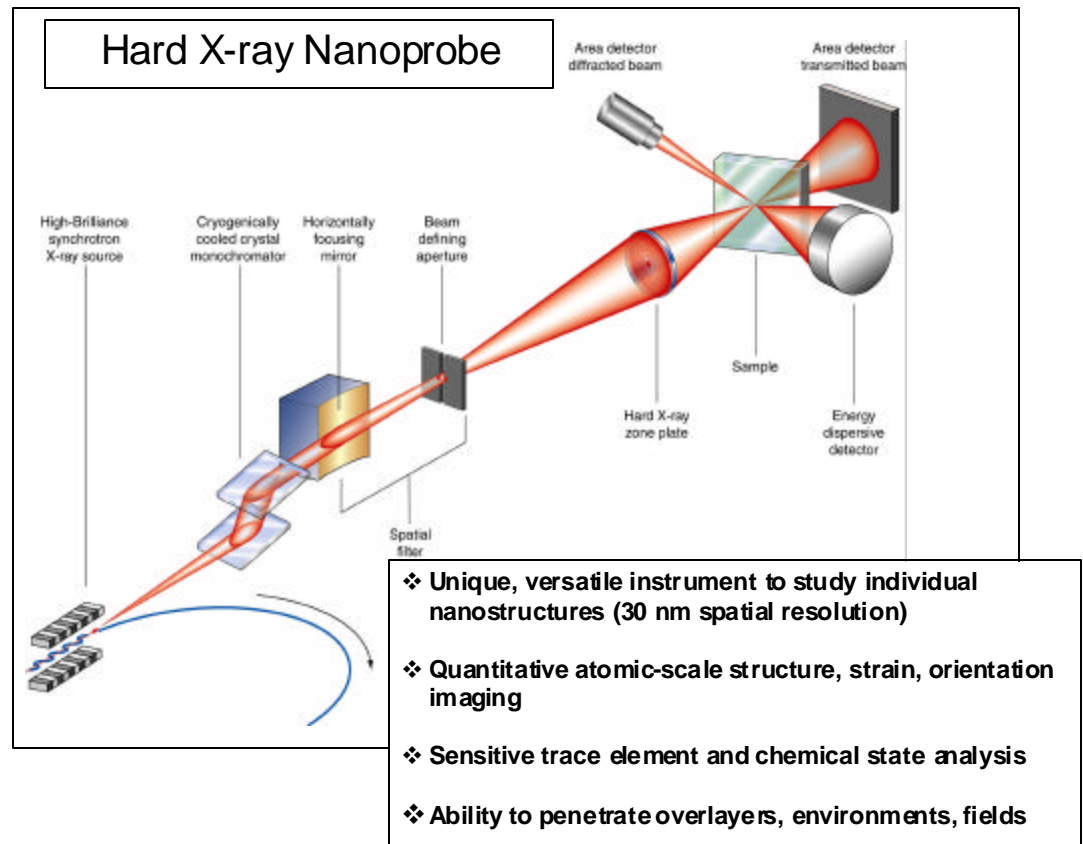
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# Automation leads to new science

- Nanoprobe
  - Scan real and reciprocal space in nanovolumes
- Adaptive optics with feedback
- Multi-parameter “smart” scans



# Readiness for Phase III

- This builds on Phase I and II for a complete reinstrumentation of all beamlines. Incremental developments will be going through Phases I and II. Education and outreach will be facilitated by an Institute for X-Ray Science and Technology, including a theory component.

# Phase III – Cost, Schedule, Scope and Management

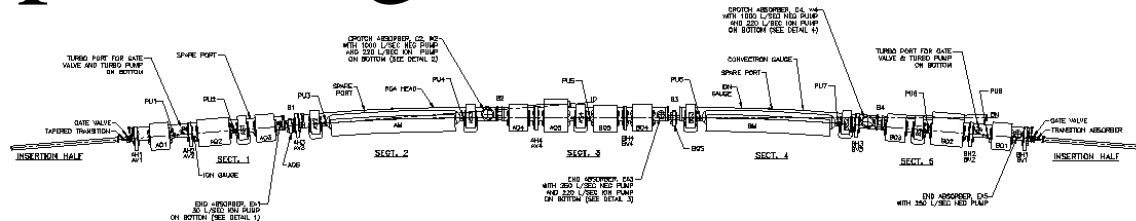
- Estimated cost for enhancements of beamlines is \$400M
- Funding should include partner users in construction, proposals and SAC oversight
- Center for X-Ray Science and Technology involved, with partner members
- Most construction activities organized by APS, operation remains APS responsibility
- Additional \$45M conventional facilities upgrades will be needed in 20-year period

# Phase IV – Super Storage Ring (2012-2020)

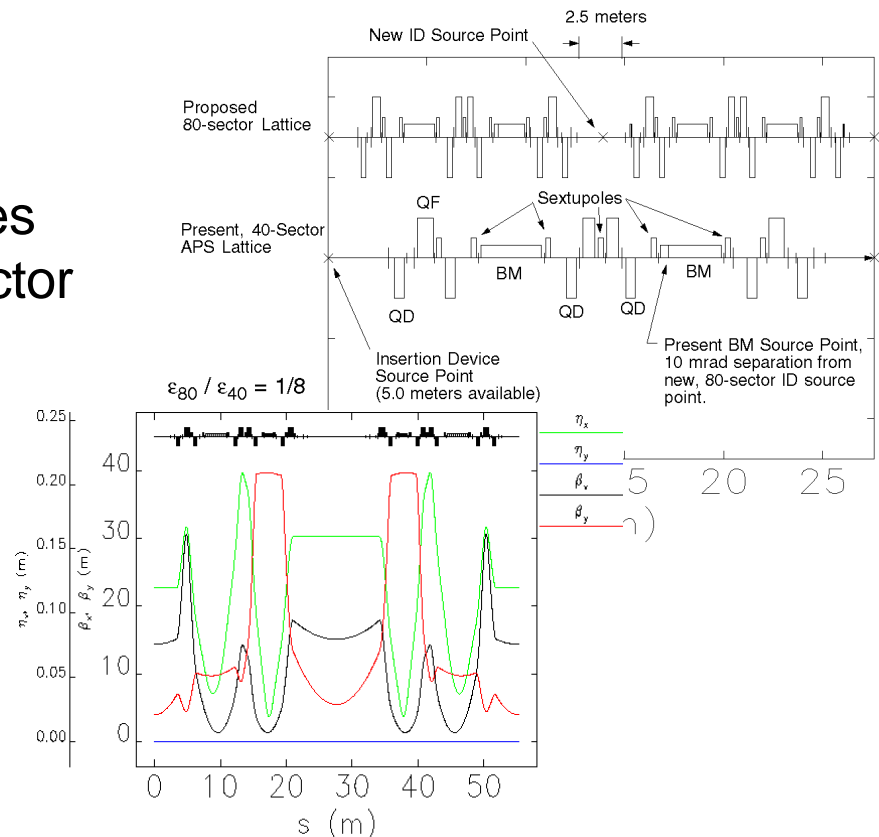
- To upgrade user capabilities and maximize value of embedded infrastructure and community
- Reduce emittance by at least a factor of 10
  - Less than 0.3 nm-rad effective emittance
  - Very short lifetime
    - Requires refined top-up and new injector
- Beam stabilization at 10nm level
- Requires new storage ring and injector
  - New injector offers 4th generation capabilities

*Preconcept stage– not yet designed*

# Super Ring - 80 Sector Lattice



- **Flexible lattice, uses existing enclosures**
- **use existing BM ports**
- **either**
  - two short insertion devices (3 - 4 meters) / double sector
- **or**
  - one long insertion device (up to 12 meters)
  - plus one hard bending magnet source



# Nano-scale Beam Stabilization

Necessary in conjunction with reduced beam emittance

- Support nanoprobe experiments
- Aggressive attack on
  - noise sources, microhertz to Megahertz
  - improved instrumentation and feedback capability

# New Injector Complex

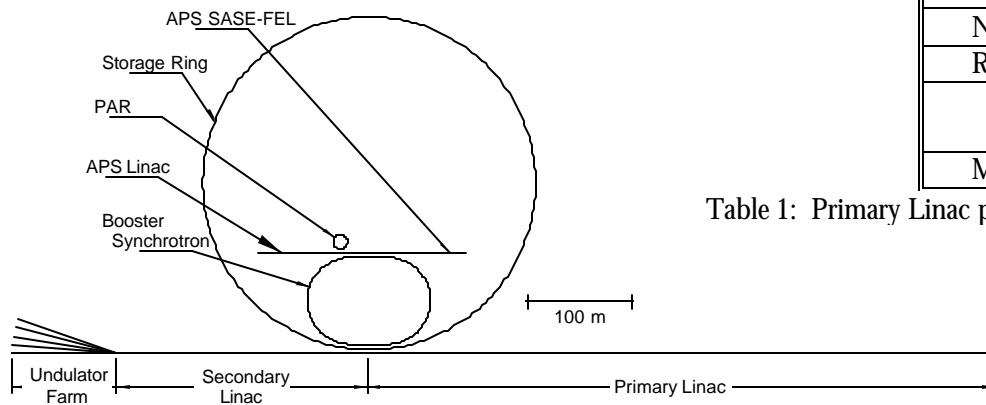
- Several possibilities for injection
  - New booster
  - LINAC source
  - Need high rep rate and emittance x10 smaller than present booster

# LINAC Augmented Light Source

- Fast injection,  
low emittance
- Offers 4<sup>th</sup> gen.
  - plus new use of  
existing injectors (UV, IR)

PARAMETER	VALUE	UNITS
General		
Total length	600	m
Cryomodules	34	
Energy gain per module	240	MeV
Total beam energy	8.16	GeV
Average gradient	13.6	MV/m
RF system		
Operational frequency	1.3	GHz
Average beam power	800	kW
Beam		
Charge per bunch	1	nC
Bunches per macropulse	1	
Normalized RMS emittance	14	$\mu\text{m}$
RMS bunch length		
At injector	10	ps
At exit of linac	< 1	ps
Macropulse repetition rate	100	Hz

Table 1: Primary Linac parameters





# The Importance of the Science

- Offers a factor of more than 10 improved brilliance to embedded beamline and user base
- Stability will enable higher performance for nano-beams etc.
- New LINAC injector will offer 4<sup>th</sup> gen. capabilities, e.g. time resolved
  - Secondary LINAC and endstations
  - Existing injector liberated for other uses
- Possible for special operating mode giving fs pulses into storage ring experiments

# Readiness for Phase IV

- In approximately 15 years, this would provide a major upgrade in capabilities
  - Unlikely that any other APS scale storage ring will be built in the foreseeable future
- Actual accelerator choices would be mandated by developments in ERL/FEL along the way
  - Could be connected to green-field FEL
  - Leverage leadership for insertion devices

# Phase IV – Cost, Schedule, Scope and Management

- Estimated cost of Super Storage Ring
  - \$350M
- Estimated cost of LINAC construction
  - \$250M
- Alternate injector approach to replace booster much less expensive, but does not offer 4<sup>th</sup> gen. or UV/IR capabilities

# How the phases are linked to the impact

- Multiple increases of more than 10x each phase in performance
  - almost 10,000 times increase in useable brilliance in 20 years
- APS will define the state-of-the-art and have a major scientific impact
- Total investment proposed is ~\$1.3B over 20 years, comparable with depreciation cost of APS (operating budget in that period >\$2B)

# Conclusion

- Phased upgrade plan maintains APS as premier 3<sup>rd</sup> generation x-ray storage ring
  - 3<sup>rd</sup> generation sources will not be obsolete!
- Embedded capabilities and user community in 15 years leads to desire for continually improved and augmented capabilities
  - Connect with 4<sup>th</sup>-generation capabilities
- Requires increased operating budgets for operational support responsibilities (only ~20% in today's dollars)

*Defining the state-of-the-art in 3<sup>rd</sup> generation x-ray sources and science*